STUDY OF BOUNDARY LAYER PARAMETERS ON ROUGH SURFACES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
in
Civil Engineering

By

SAMIR KUMAR SETHI

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "Study of Boundary Layer Parameters on Rough surfaces" submitted by Sri Samir Kumar Sethi in partial fulfillment of his requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any other Institute/University for the award of any Degree or Diploma.

Date:

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Rourkela

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CONTENTS

ABSTRACT

When real fluid flows past a solid body or a solid wall, the fluid particles adhere to the boundary and condition of no slip occurs. This means that the velocity of fluid close to the boundary will be same as that of boundary. If the boundary is stationary, the velocity of fluid at the boundary will be zero. Further away from the boundary, the velocity will be higher and as a result of this variation of velocity, the velocity gradient will exist. The velocity of fluid increases from zero velocity on the stationary boundary to the free stream velocity of the fluid in the direction normal to the boundary. This variation of velocity from zero to free stream velocity in the direction normal to the boundary takes place in a narrow region in the vicinity of solid boundary. This narrow region of fluid is called Boundary Layer.

Three main parameters (described below) that are used to characterize the size and shape of a boundary layer are the boundary layer thickness, the displacement thickness, and the momentum thickness.

The *displacement thickness* is the distance a streamline just outside the boundary layer is displaced away from the wall compared to the inviscid solution. Another way to describe it is the distance the wall would have to be displaced to yield the same solution for flow outside the boundary layer as the boundary layer equations yield.

The *momentum thickness*, is the distance that, when multiplied by the square of the free-stream velocity, equals the integral of the momentum defect across the boundary layer.

In our thesis, we have obtained the boundary layer parameters and velocity ratio on smooth and different types of rough surfaces by using Air Flow Bench. The sand papers of different grain sizes have been considered as rough surfaces.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

When a real fluid flows over a solid surface, there is no slip at the surface. The fluid in the immediate contact with a surface moves with it, and the relative velocity increases from zero at the surface to the velocity in the free stream through a layer of fluid which is called Boundary Layer.

The *boundary layer effect* occurs at the field region in which all changes occur in the flow pattern.The boundary layer distorts surrounding nonviscous flow. It is a phenomenon of viscous forces. This effect is related to the Reynolds number.

Laminar boundary layers come in various forms and can be loosely classified according to their structure and the circumstances under which they are created. The thin shear layer which develops on an oscillating body is an example of a Stokes layer, while the Blasius boundary layer refers to the well-known similarity solution for the steady boundary layer attached to a flat plate held in an oncoming unidirectional flow.

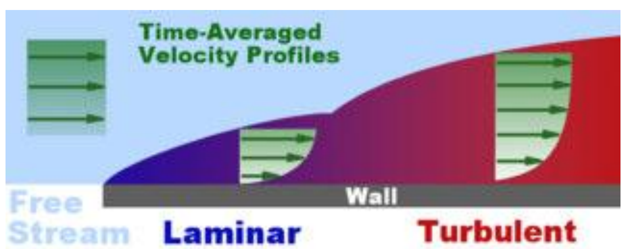


Fig. 1.1

Consider a steady flow over a flat smooth plate where the streaming velocity U is constant over the length of the plate. It is found that the thickness of the boundary layer grows along the length of the plate as shown above.

The motion in the boundary layer is laminar at the start, but if the plate is sufficiently long, a transition to turbulences observed. This transition is produced by small disturbances which, beyond certain distances , grows rapidly and merge to produce the apparently random fluctuations of velocity which are characteristics of turbulent motions .T he parameter which characterizes the motion is the Re_x based on distance x from the leading edge .

$$Re_x = \frac{U_x}{\nu}$$

The nature of the process of transition n renders it prone to factors such as turbulence in the free stream and surface roughness of the boundary, so it is not possible to give a single value of Re_x at which transition will occur, but it is usually found in the range of
$1 x 10^5$ to $5 x 10^5$.

In this project, I would study the effect of surface roughness on different boundary layer parameters. This would be attained by using sand papers of various grain sizes . The extensive experimentation on different rough surfaces will enables to study the changes in boundary layer parameters from smooth to rough surfaces. It will help in the assessment of the boundary layer characteristics for a given roughness. This may be used in aerodynamic design.

CHAPTER 2

CONCEPTS OF BOUNDARY LAYER

CONCEPTS OF BOUNDARY LAYER

2.1 DEFINITION OF THICKNESS

A little consideration shows that the boundary layer thickness δ, as the thickness where the velocity reaches the free stream value, is not an entirely satisfactory concept. The velocity in the boundary layer increases towards U is an asymptotic manner, so the distance y at which we might consider the velocity to have reached U will depend on the accuracy of measurement.

A much more useful concept of thickness is the displacement thickness δ^*. This is defined as the thickness by which fluid outside the layer is displaced away from the boundary by the existence of the layer, by the streamline approaching B in the figure.

Here, the distribution of velocity u within the layer is depicted as a function of distance y from the boundary as curve OA. If there was no boundary layer, the free stream velocity U would persist right down to the boundary (CA).

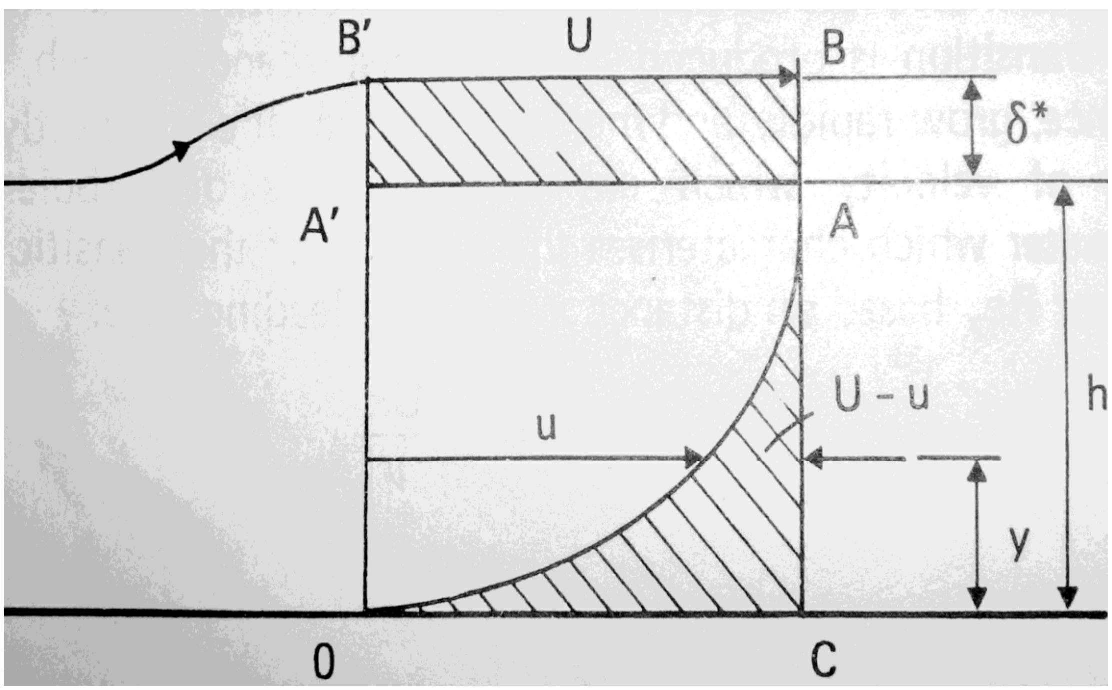


Fig. 2.1

2.2 EFFECT OF PRESSURE GRADIENT

If the free stream is accelerating or decelerating, substantial changes take place in the boundary layer development. For an accelerating free stream, the pressure falls in the direction of flow, the pressure gradient being given by differentiating Bernoulli's Equation in the free stream as,

$$\frac{dP}{dx} = -\rho U \frac{dU}{dx}$$

The boundary layer grows less rapidly than in zero pressure gradient and transition to turbulence is inhibited. For the decelerating free stream, the reverse effects are observed. The boundary layer grows more rapidly and the shape factor increases in the down stream direction.

The pressure rises in the direction of flow, and this pressure rise tends to retard the fluid in the boundary layer more severely than that in the main stream since it is moving less quickly. Energy diffuses from the free stream through the outer part of the boundary layer down towards the surface to maintain the forward movement against the rising pressure.

However, if the pressure gradient is sufficiently steep, the diffusion is insufficient to sustain the forward movement, and the flow along the surface reverses, forcing the main stream to separate.

It is this separation, or stall as it is sometimes called, which leads to the main component of drag on bluff bodies and to the collapse of the lift force on an aerofoil when the angle of incidence is excessive.

2.3 ROUGH SURFACES

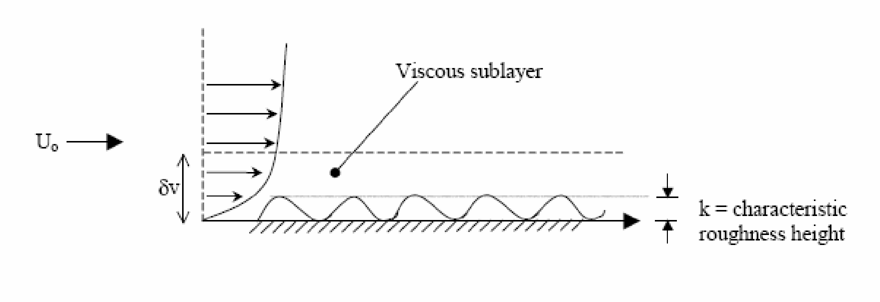


Fig. 2.2

To account for roughness we first define an ‘equivalent sand roughness’ coefficient k (units: [L]), a measure of the characteristic roughness height.
The parameter that determines the significance of the roughness k is the ratio

$$\frac{k}{\delta}$$

Fig. 2.3

CHAPTER 3

TEMPERATURE EFFECTS

TEMPERATURE EFFECTS

3.1 EFFECT ON AIR DENSITY

The air density ρ_a may be calculated from the barometric pressure ρ and the temperature T from the gas equation

$$\rho / \rho_a = RT$$

in which the value of the gas constant R for the dry air is

$$R = 287.2 \text{ J/kg K}$$

Or $$R = 287.2 \text{ Nm/kg K}$$

J indicates the SI unit of energy, the joule (which is identical with the Newton-metre or Nm) and K indicates the unit of temperature, the Kelvin. If t represents temperature in ^{o}C, then,

$$T = t + 273.15$$

Thus from the above equations

$$\rho_a = \rho/[287.2(t+273.15)] \text{ kg/m}^3$$

$10^{-5}\rho$ (N/m^2)	0.95	1.00	1.01325	1.05
t ^{o}C				
10	1.168	1.230	1.246	1.291
15	1.148	1.208	1.224	1.269
20	1.128	1.188	1.203	1.247
25	1.109	1.168	1.183	1.226

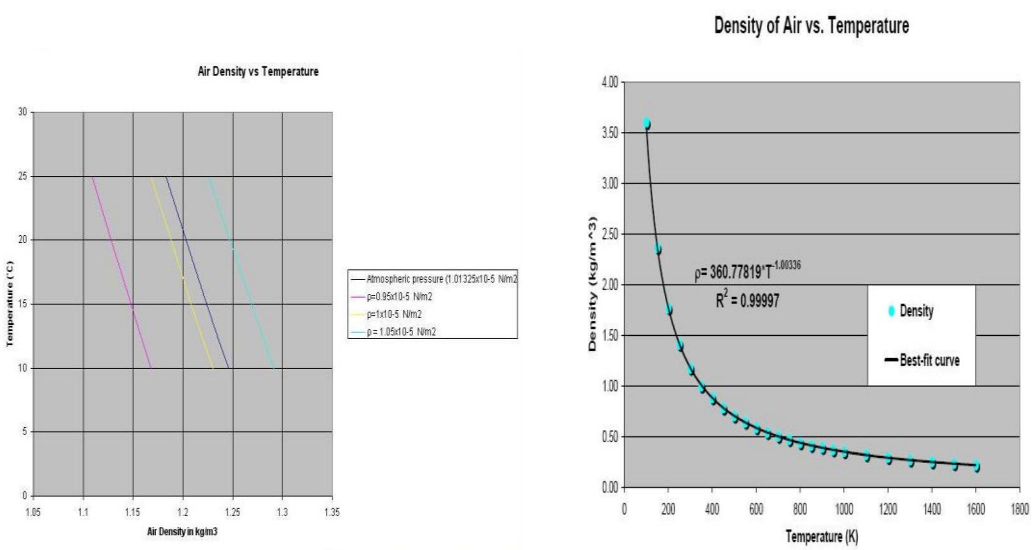


Fig.3.1

3.2 EFFECT ON KINEMATIC VISCOSITY

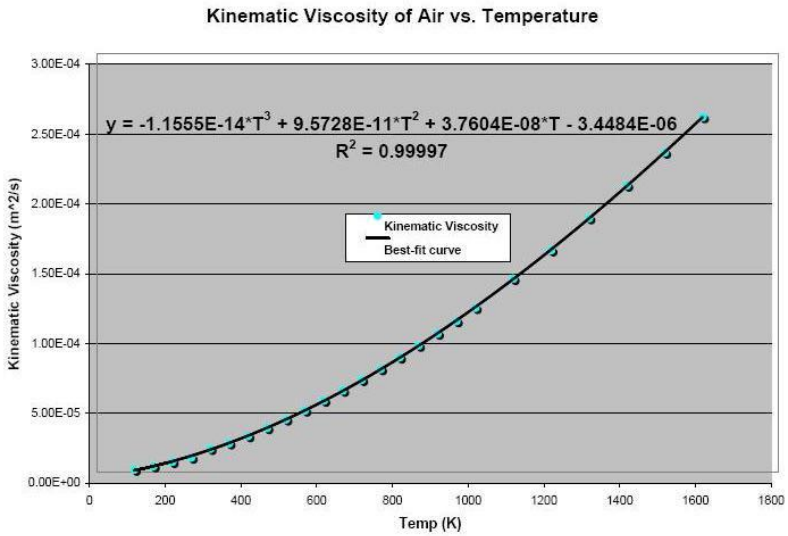


Fig. 3.2

The above graph clearly shows that kinematic viscosity increases with the increase in temperature. But in our project, this factor was not considered due to the fact that there is negligible increase in kinematic viscosity for low temperature (between 300.15K to 306.15 K).

CHAPTER 4

TEST APPARATUS

TEST APPARATUS

The apparatus used was AIR FLOW BENCH AF10a.

4.1 AIR FLOW BENCH AF10a

Fig. 4.1

4.2 INTRODUCTION

This equipment was devised by Professor E. Markland, former Head of Department of Mechanical Engineering, University of Cardiff, for an introductory course in Air Flow.

4.3 DESCRIPTION

AF10 Airflow Bench is in the nature of a simple miniature wind tunnel; it provides a controlled airstream for experiments which use matching test equipment.

The AF10 Airflow Bench comprises a fan which draws air from the atmosphere and delivers it along a pipe to an airbox which is above the test area. In the pipe is a valve which may be used to regulate the discharge from the fan.

There is a rectangular slot in the underside of the airbox to which various contraction sections may be fitted. The air accelerates as it flows from the box along the contracting passage, and any unsteadiness or unevenness of the flow at the entry becomes proportionately reduced as the streaming velocity increases towards the test section, which is fitted at the exit of the contraction. Discharge from the test section is in most cases directed towards the bench top, in which a circular hole is provided to collect the air so that it may be led through a duct to the rear of the bench. If necessary, the exhaust can be taken right out of the laboratory (for example, if, use is to be made of smoke traces) with the exhaust duct extended as necessary and an extractor fan fitted at the downstream end if required.

The bench is mounted on wheels with jacking screws so that it may be moved without difficulty. It requires an earthed, AC single-phase electrical supply.

A fan delivers atmospheric air via an iris valve to a plenum chamber. The iris valve is used for flow control. Various test facilities may be attached to a 350mm x 300mm opening in the plenum chamber. An aerodynamically shaped contraction is supplied with the bench to provide an entry to a number of experiments, having 100mm x 50mm working section. Extensive use is made of toggle fasteners so that no tools are required for fitting the various experiments to the bench. Discharge from the experiments is normally downwards, the exhaust air passing through a pipe let into the bench top and terminating at the rear. This arrangement allows flexible ducting to be fitted (when experiments using smoke are in progress) to lead waste smoke safely away.

4.4 THE INCLINABLE MULTITUBE MANOMETER (AF10A)

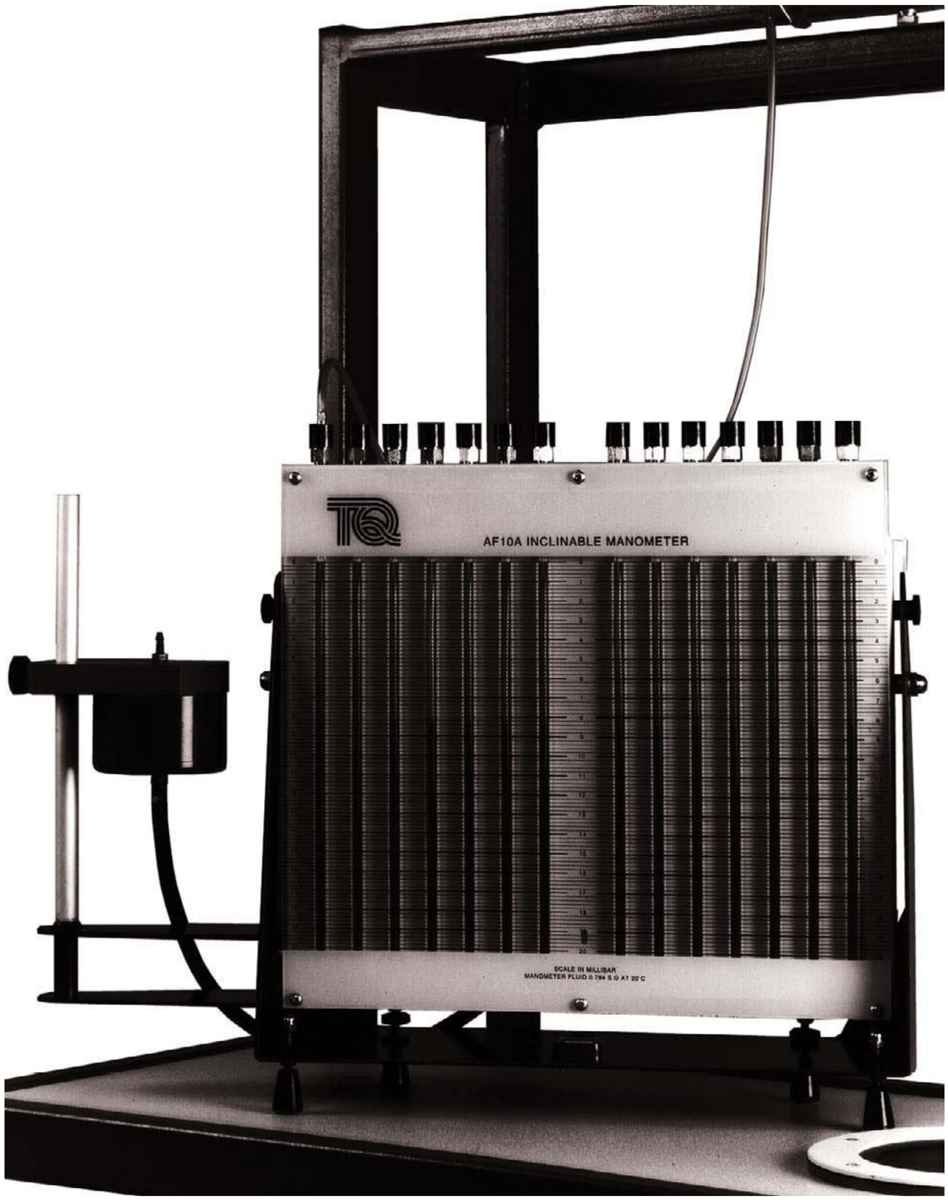


Fig. 4.2

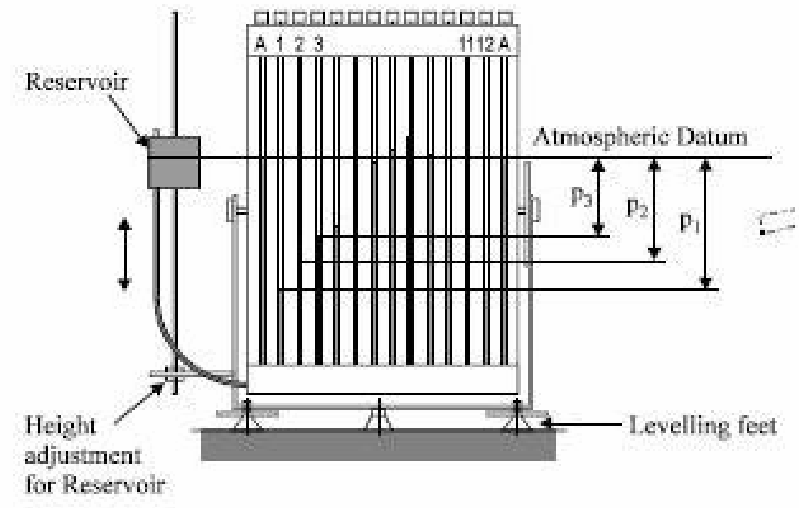


Fig. 4.3

The reservoir for the manometer liquid is mounted on a vertical rod so that it may be set to a convenient height. It is recommended that the manometer tubes at the two sides, marked A in above figure, and the reservoir connection, be normally left open to atmospheric pressure. Pressures p1, p2, p3 ... in tubes 1, 2, 3 are then gauge pressures, measured relative to an atmospheric datum. (Pressures relative to some other datum may be obtained by connecting the reservoir and the manometer tubes marked A to the required datum).

The usual manometer liquid is water, although in some instances a paraffin-based liquid of low specific gravity is used. To aid visibility, the water may be coloured by a dye which is supplied with the equipment. The specific gravity of the water is not significantly altered by addition of the dye. To fill, the reservoir is positioned about halfway up the bar, and the fitting at the top is unscrewed. Using the funnel provided, manometer liquid is poured in until the level is halfway up the scale. Any air bubbles from the manometer tubes are then removed by tapping the inlet pipe, or by blowing into the tops of the tubes.

The manometer scale is usually graduated in mm. Pressure readings taken in terms of mm of water may be converted to units of millibar (mb) from the relationship:

1 mm water = 0.0981 mb (1mb=100 Pa)

$\Delta p = p - p_a$

The manometer must be levelled before taking readings. This can be done by using the adjustable feet, while observing the spirit level and the manometer liquid levels across all of the tubes under static conditions.

It is possible that, as the air speed is increased, liquid may be driven out of the tops of the manometer tubes, or drawn down into the manifold at the base. The connection between tapping points and the manometer would then have to be cleared, or the reservoir may need to be refilled. It is therefore advisable, before starting a test, to guard against these eventualities by adopting the following setting-up procedure.

With the fan at rest and the bench valve closed, the manometer should be set to the vertical position, with the liquid level at about mid-height. The fan should then be started, and the air speed raised gradually by carefully opening the bench valve, while observing the levels in the manometer tubes. As the pressures in the various tubes change, the reservoir level should be moved up or down, as found to be necessary to keep all the liquid levels within the bounds of the scale. A good setting would use most of the scale at full airspeed. If, however, only a small proportion of the scale is used, the procedure should be repeated with the manometer inclined to the vertical.

To fill the manometer position the reservoir approximately halfway up the side bar. Unscrew the fitting on top of the reservoir and, using the funnel provided, pour in a quantity of water (and dye if required). Continue until the water level is halfway up the manometer scale. Check the system for air bubbles, and remove by tapping the inlet pipe, or by gently blowing into the manometer tube at the top.

Having decided on a suitable manometer setting, a final height adjustment of the reservoir should then be made to bring the datum reading at tubes A to some convenient scale graduation - such as, for example, 120 mm. This is the value which has to be subtracted from the scale readings of the pressures p1, p2... to obtain gauge pressures. It is much easier to perform the subtraction with a datum that has been conveniently chosen.

4.5 BOUNDARY LAYER APPARATUS AF14.

A flat plate is placed in the l00 mm x 50 mm transparent working section so that a boundary layer forms along it. A sensitive, wedge shaped pitot tube mounted in a micrometer traverse allows velocity measurements to be made in the boundary layer. Both laminar and turbulent layers may be formed. Experiments which may be carried out include the measurement of the velocity profile:

1. In laminar and turbulent boundary layers.

2. In the boundary layer on rough and smooth plates.

3. In the boundary layer at various distances from the leading edge of the plate.

4. In the boundary layer on plates subiect to an increasing or decreasing pressure gradient in the direction of flow (using the removable duct liners supplied).

DIMENSIONS & WEIGHTS

AF10

Dimension: 1100 x 1000 x 2210mm

Weight: 120kg Gross: 2.43m^3; 260kg.

AF14

Dimension: 0.2m^3

Weight:10kg

CHAPTER 5

TEST PROCEDURE

5.1 TEST PROCEDURE

1.The figure shows the arrangement of the test section attached to the outlet of contraction of the airflow bench.

2.A flat plate is placed at the mid height of the section, with a sharpened edge facing the oncoming flow. Once side of the plate is smooth and the other is rough so that by turning the plate over, results may be obtained on both types of surfaces.

3.A fine pitot tube may be traversed through the boundary layer at a section near the downstream edge of the plate. This tube is very delicate instrument which must be handled with extreme care if damage is to be avoided. The end of the tube is flattened so that it presents a narrow slit opening to the flow.

4.The traversing mechanism is spring loaded to prevent backlash and a linear scale reading is used to indicate the displacement of the pitot tube.

Fig. 5.1

5 . To obtain a boundary layer velocity profile, the pitot tube was set touching the smooth surface of the plate and the wind speed is established by bringing the pressure P_o in the air box to the required value. Readings of total pressure P measured by pitot tube are then recorded over a range of settings of the linear scale as the tube is traversed towards the test section surface.

6.Similarly, readings were taken on a smooth surface followed by five different rough surfaces of grain sizes 300 microns, 250 microns, 180 microns, 150 microns & 125 microns.

CHAPTER 6

OBSERVATIONS & CALCULATIONS

6.1 <u>OBSERVATIONS</u>

1.At first the reading increased constantly along a certain length indicating that the traverse has been in the boundary layer region. Reading were taken at an interval of 1mm till the readings reaches to a constant value for a certain length along the section.

2.On further movement, the readings substantially decreased indicating that the pitot tube has entered the boundary layer region of the test section.

Similarly, readings at different velocities and then for the rough surface were taken.

Damping would have been provided by squeezing the connecting plastic tube but, it could lead to false readings. So, the unsteady readings were observed and then their mid reading were taken by us.

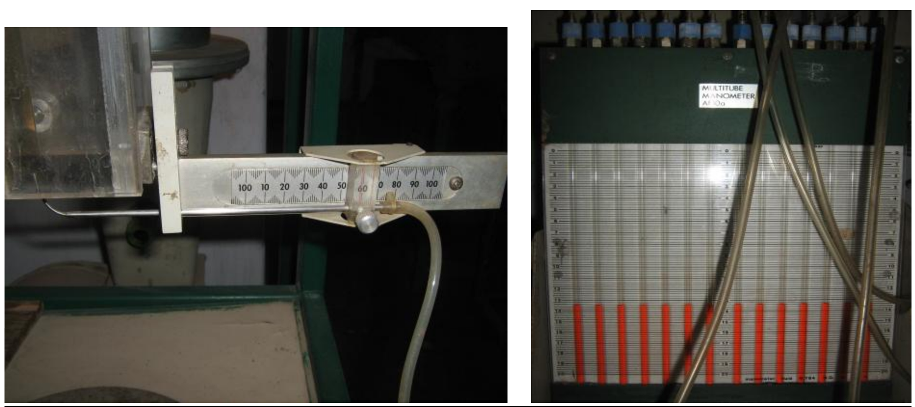


Fig. 6.1

6.2 ROUGH SECTION

The rough section consists of sand paper of known grain size.

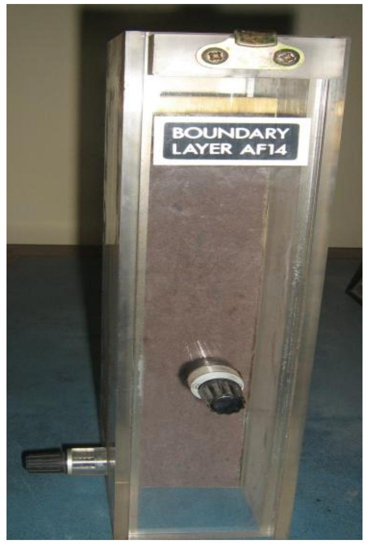


Fig. 6.2

6.3 PLANE SECTION

It consists of a plane metal section.

Fig. 6.3

6.4 EXPERIMENTAL DATA

Length of plate from leading edge to traverse section, L= 0.25m.

Thickness of pitot tube at tip, 2t=0.4mm.

Hence, displacement of tube centre from surface when in contact, t=0.2mm.

Values of u/U are found from equation given below:

$$(u/U) = \sqrt{(P_t/P_o)}$$

Where P_t is Pitot Pressure and P_o is the pitot tube reading in the free stream.

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

6.5 SMOOTH SURFACE

Velocity 17.53 m/s.

Room Temperature: 33°C (306 K)

Density of air at 33°C = 1.151 kg/m^3

Air flow bench pressure (P_o) = 176.8398N/mm2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 17.53 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

$$Re = 2.80 \times 10^5$$

Velocity 23.11m/s.

Room Temperature: 33°C (306 K)

Density of air at 33°C = 1.151 kg/m^3

Air flow bench pressure(P_o): 307.547N/mm2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 23.11 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

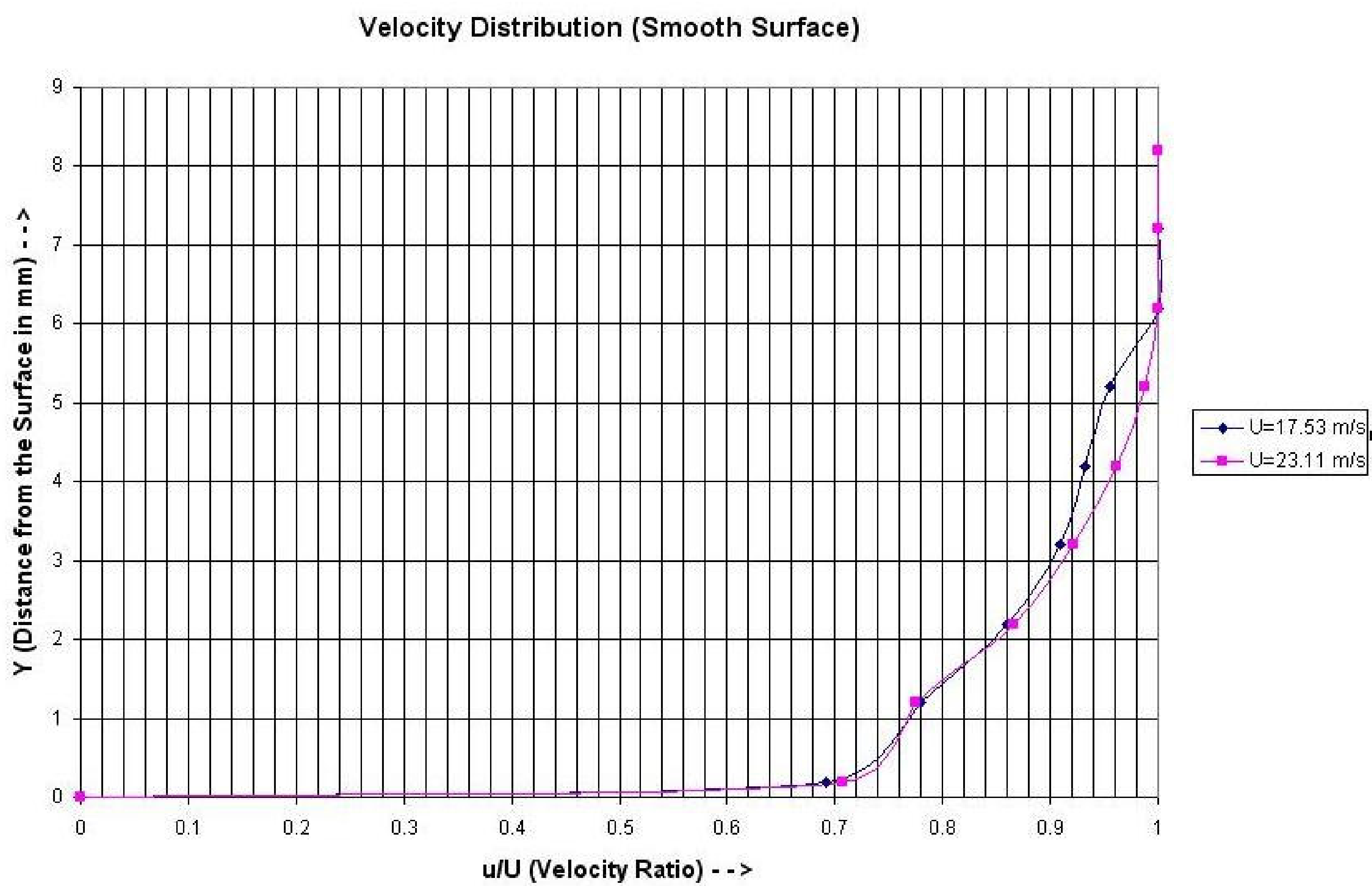
$$Re = 3.695 \times 10^5$$

Table 6.1: Smooth Surface

Smooth Surface	Temperature=33`C	P_o=176.8398N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 33C= 1.151kg/m^3	**U=17.53m/s**	Reynold's no. , Re=2.80*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
39	0.2	12.1	17.1	84.575568	0.691564075	0.213303205
40	1.2	12.4	17.4	107.641632	0.780189498	0.171493845
41	2.2	12.7	17.7	130.707696	0.859726954	0.120596519
42	3.2	12.9	17.9	146.085072	0.908893259	0.082806303
43	4.2	13	18	153.77376	0.932504808	0.062939591
44	5.2	13.1	18.1	161.462448	0.955533086	0.042489608
45	6.2	13.3	18.3	176.839824	1	0
46	7.2	13.3	18.3	176.839824	1	0

Table 6.2:

Smooth Surface	Temperature=33`C	Po=307.547N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 33C=1.151kg/m^3	**U=23.11m/s**	Reynold's no., Re=3.695*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
39	0.2	13.2	18.2	153.77376	0.707106781	0.207106781
40	1.2	13.6	18.6	184.528512	0.774596669	0.174596669
41	2.2	14.2	19.2	230.66064	0.866025404	0.116025404
42	3.2	14.6	19.6	261.415392	0.921954446	0.071954446
43	4.2	14.9	19.9	284.481456	0.961769203	0.036769203
44	5.2	15.1	20.1	299.858832	0.987420883	0.012420883
45	6.2	15.2	20.2	307.54752	1	0
46	7.2	15.2	20.2	307.54752	1	0
47	8.2	15.2	20.2	307.54752	1	0



Velocity Distribution (Smooth Surface)
Y (Distance from the Surface in mm) - - >
u/U (Velocity Ratio) - - >
U=17.53 m/s
U=23.11 m/s
0
1
2
3
4
5
6
7
8
9
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Fig. 6.4

6.6 Grain Size: 300 micron [redacted].

Velocity 17.78 m/s.

Room Temperature: 29^{o}C (301 K)

Air flow bench pressure(P_o): 184.528 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 17.78 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

$$Re = 2.882 \times 10^5$$

Velocity 23.24 m/s.

Room Temperature: 29^{o}C (301 K)

Air flow bench pressure(P_o): 315.236 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 23.24 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

$$Re = 3.767 \times 10^5$$

Table 6.3: Rough surface (300 microns)

Rough Surface (300 microns)	Temperature=29`C	Po=184.528N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 29`C =1.167kg/m^3	**U=17.78m/s**	Reynold's no., Re=2.882*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	11.7	16.7	53.820816	0.540061725	0.248395058
33	1.2	12	17	76.88688	0.645497224	0.228830558
32	2.2	12.2	17.2	92.264256	0.707106781	0.207106781
31	3.2	12.5	17.5	115.33032	0.790569415	0.165569415
30	4.2	12.8	17.8	138.396384	0.866025404	0.116025404
29	5.2	13	18	153.77376	0.912870929	0.079537596
28	6.2	13.1	18.1	161.462448	0.935414347	0.060414347
27	7.2	13.3	18.3	176.839824	0.97894501	0.020611677
26	8.2	13.4	18.4	184.528512	1	0
25	9.2	13.4	18.4	184.528512	1	0

Table 6.4:

Rough Surface (300 microns)	Temperature=29`C	Po=315.236N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 29`C =1.167kg/m^3	**U=23.24m/s**	Reynold's no., Re=3.767*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	12.1	17.1	84.575568	0.51796977	0.249677087
33	1.2	12.4	17.4	107.641632	0.58434871	0.242885295
32	2.2	12.9	17.9	146.085072	0.680745646	0.217331012
31	3.2	13.5	18.5	192.2172	0.780868809	0.171112712
30	4.2	14	19	230.66064	0.855398923	0.123691606
29	5.2	14.4	19.4	261.415392	0.910641693	0.0813734
28	6.2	14.8	19.8	292.170144	0.962719725	0.035890456
27	7.2	14.9	19.9	299.858832	0.97530483	0.024085318
26	8.2	15.1	20.1	315.236208	1	0
25	9.2	15.1	20.1	315.236208	1	0

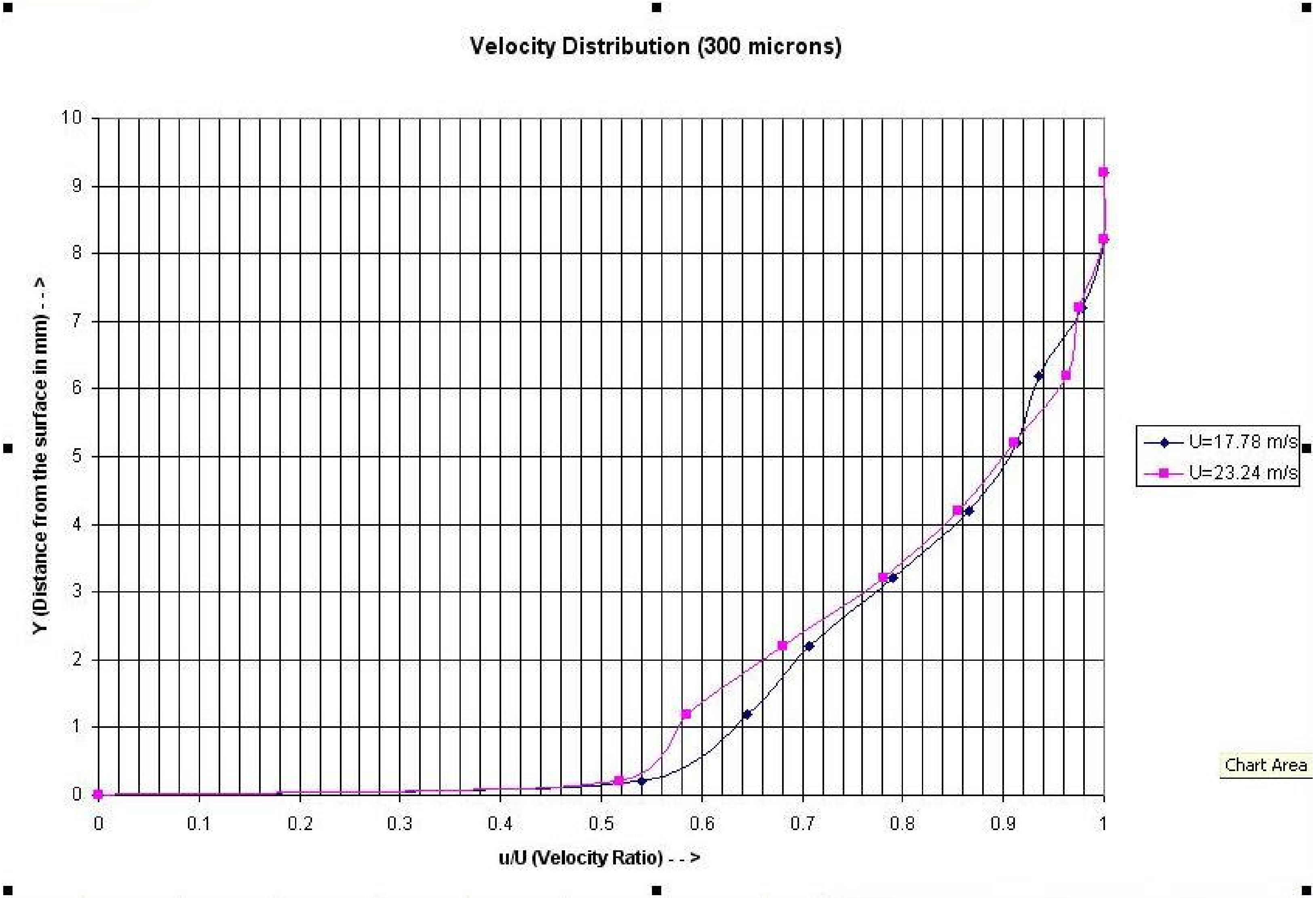

Velocity Distribution (300 microns)
Y (Distance from the surface in mm) - - >
u/U (Velocity Ratio) - - >
U=17.78 m/s
U=23.24 m/s
Chart Area
0
1
2
3
4
5
6
7
8
9
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Fig. 6.5

6.7 Grain Size: 250 microns.

Velocity 17.53 m/s.

Room Temperature: 33^oC (306.15 K)

Air flow bench pressure(P_o): 176.8398 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 17.53 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

$$Re = 2.8 \times 10^5$$

Velocity 23.97 m/s.

Room Temperature: 33^oC (306.15 K)

Air flow bench pressure(P_o): 330.6135N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 23.97 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

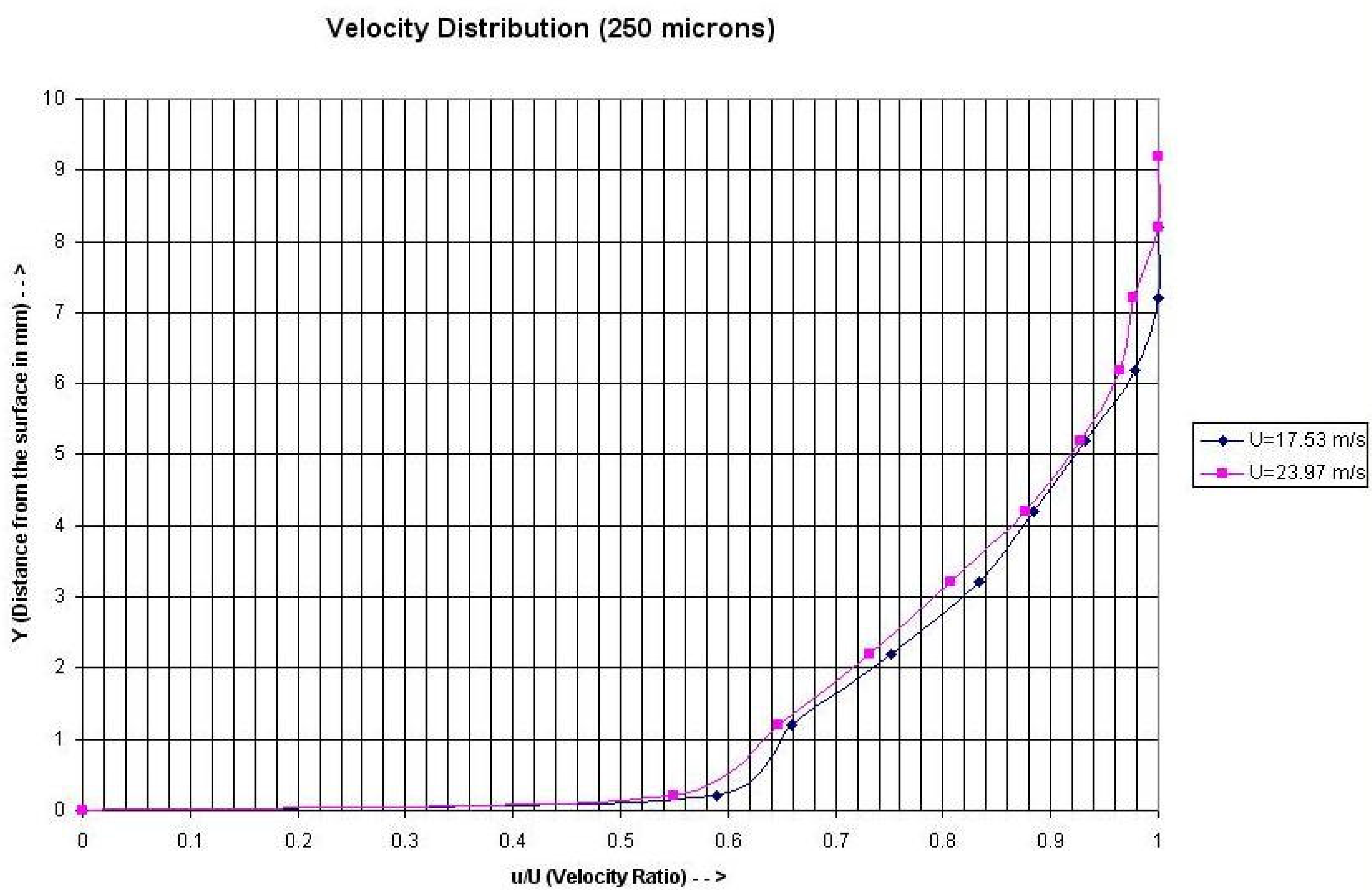
$$Re = 3.831 \times 10^5$$

Table 6.5: Rough Surface (250 microns)

Rough surface (250 microns)	Temperature=33`C	Po=176.8398N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 33`C =1.151kg/m^3	**U=17.53m/s**	Reynold's no., Re=2.80*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	11.8	16.8	61.509504	0.589767825	0.241941738
33	1.2	12	17	76.88688	0.659380473	0.224597865
32	2.2	12.3	17.3	99.952944	0.751809412	0.18659202
31	3.2	12.6	17.6	123.019008	0.834057656	0.138405482
30	4.2	12.8	17.8	138.396384	0.884651737	0.102043041
29	5.2	13	18	153.77376	0.932504808	0.062939591
28	6.2	13.2	18.2	169.151136	0.978019294	0.021497555
27	7.2	13.3	18.3	176.839824	1	0
26	8.2	13.3	18.3	176.839824	1	0

Table 6.6:

Rough Surface (250 microns)	Temperature=33`C	Po=330.6135N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 33`C =1.151kg/m^3	**U=23.97m/s**	Reynold's no., Re=3.831*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	12.3	17.3	99.952944	0.549841415	0.247515833
33	1.2	12.8	17.8	138.396384	0.646996639	0.228391988
32	2.2	13.3	18.3	176.839824	0.731357451	0.19647373
31	3.2	13.8	18.8	215.283264	0.806946585	0.155783794
30	4.2	14.3	19.3	253.726704	0.876037591	0.10859573
29	5.2	14.7	19.7	284.481456	0.92761259	0.067147473
28	6.2	15	20	307.54752	0.964485644	0.034253086
27	7.2	15.1	20.1	315.236208	0.976467292	0.02297892
26	8.2	15.3	20.3	330.613584	1	0
25	9.2	15.3	20.3	330.613584	1	0



Velocity Distribution (250 microns)
Y (Distance from the surface in mm) - - >
u/U (Velocity Ratio) - - >
U=17.53 m/s
U=23.97 m/s
0
1
2
3
4
5
6
7
8
9
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Fig.6.6

6.8 Grain Size: 180 micron[redacted].

Velocity 18.15 m/s.

Room Temperature: 29^{o}C (302.15 K)

Air flow bench pressure(P_o): 192.2172 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 18.15 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

$$Re = 2.943 \times 10^5$$

Velocity 24.04 m/s.

Room Temperature: 28^{o}C (301.15 K)

Air flow bench pressure(P_o): 338.302 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 24.04 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

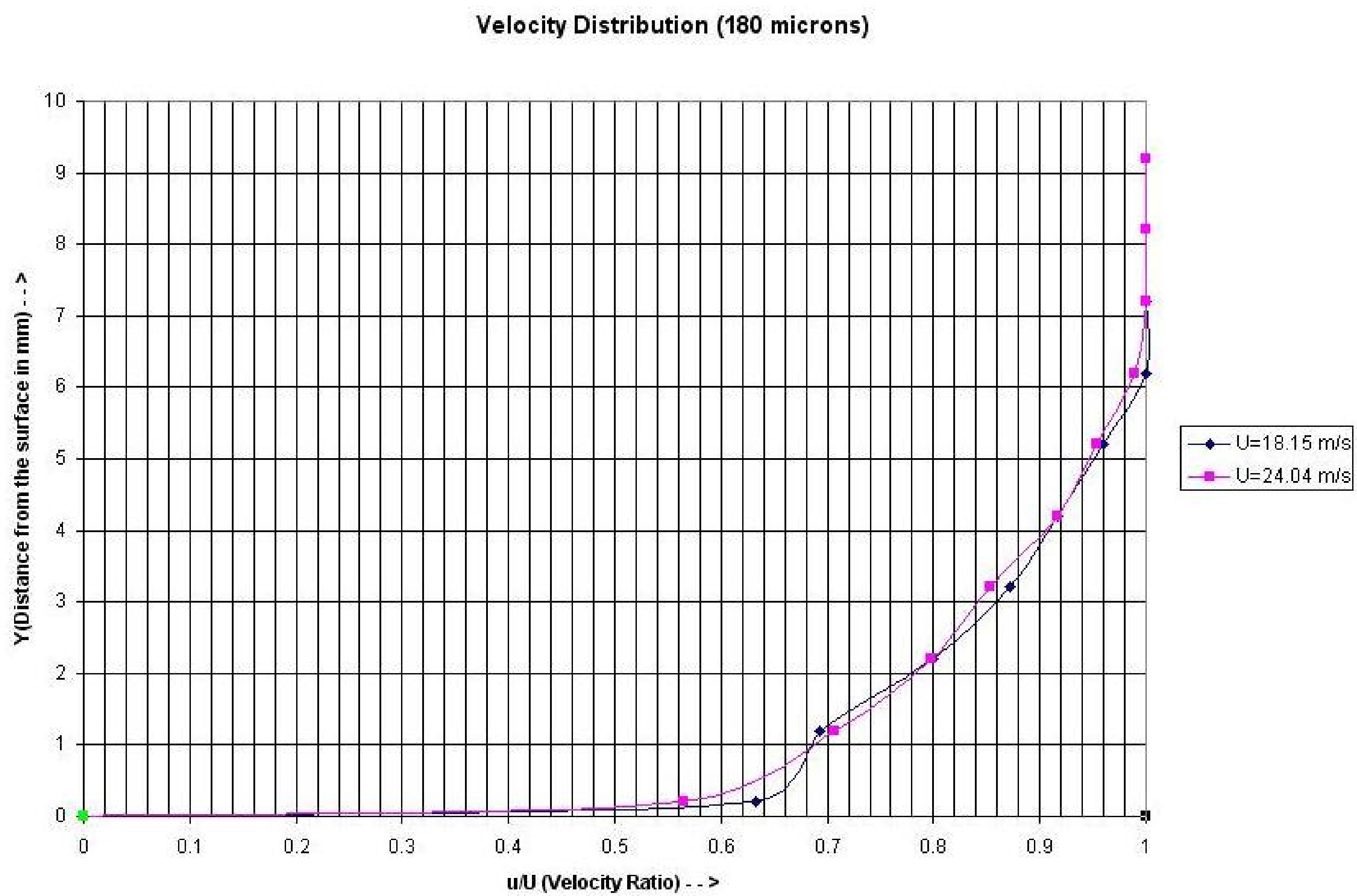
$$Re = 3.909 \times 10^5$$

Table 6.7: Rough Surface (180 microns)

Rough Surface (180 microns)	Temperature=29`C	Po=192.2172N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 29`C =1.167kg/m^3	**U=18.15m/s**	Reynold's no., Re=2.943*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	12	17	76.88688	0.632455532	0.232455532
33	1.2	12.2	17.2	92.264256	0.692820323	0.212820323
32	2.2	12.6	17.6	123.019008	0.8	0.16
31	3.2	12.9	17.9	146.085072	0.871779789	0.111779789
30	4.2	13.1	18.1	161.462448	0.916515139	0.076515139
29	5.2	13.3	18.3	176.839824	0.959166305	0.039166305
28	6.2	13.5	18.5	192.2172	1	0
27	7.2	13.5	18.5	192.2172	1	0

Table 6.8:

Rough Surface (180 microns)	Temperature=28`C	Po=338.302N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 28`C =1.171kg/m^3	**U=24.04m/s**	Reynold's no., Re=3.909*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	12.4	17.4	107.641632	0.564076075	0.245894257
33	1.2	13.2	18.2	169.151136	0.707106781	0.207106781
32	2.2	13.8	18.8	215.283264	0.797724035	0.161360399
31	3.2	14.2	19.2	246.038016	0.852802865	0.125530138
30	4.2	14.7	19.7	284.481456	0.917010955	0.076101864
29	5.2	15	20	307.54752	0.953462589	0.04437168
28	6.2	15.3	20.3	330.613584	0.988571053	0.011298326
27	7.2	15.4	20.4	338.302272	1	0
26	8.2	15.4	20.4	338.302272	1	0
25	9.2	15.4	20.4	338.302272	1	0



Velocity Distribution (180 microns)
Y(Distance from the surface in mm) - - >
u/U (Velocity Ratio) - - >
U=18.15 m/s
U=24.04 m/s
0
1
2
3
4
5
6
7
8
9
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Fig:-6.7

6.9 Grain Size: 150 microns.

Velocity 17.44 m/s.

Room Temperature: 30^{o}C (303.15 K)

Air flow bench pressure(P_o): 176.84 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 17.44 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

$$Re = 2.817 \times 10^5$$

Velocity 23.24 m/s.

Room Temperature: 29^{o}C (302.15 K)

Air flow bench pressure(P_o): 315.236 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 23.24 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

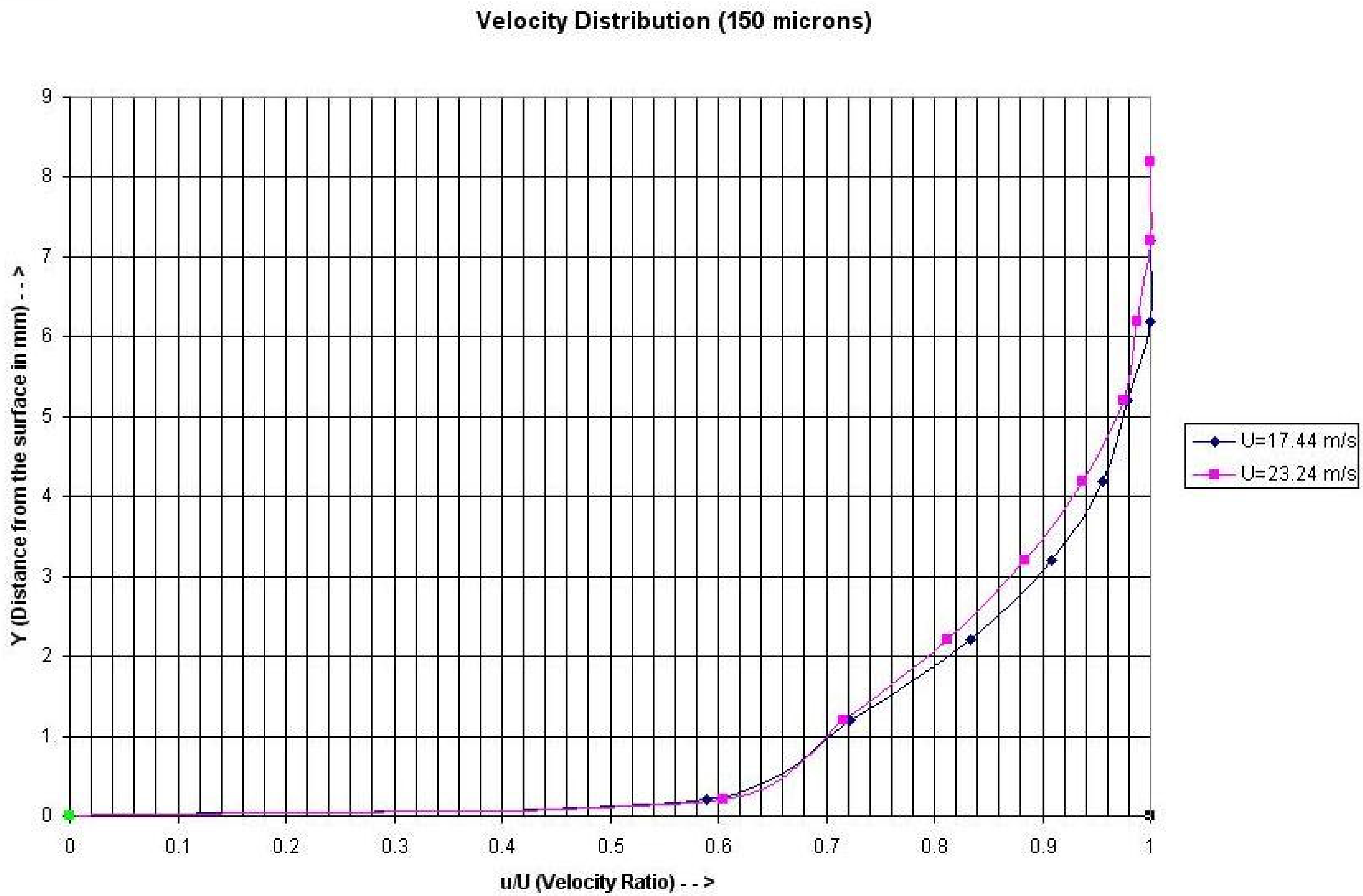
$$Re = UL/\nu$$

$$Re = 3.767 \times 10^5$$

Table 6.9: Rough Surface (150 microns)

Rough Surface (150 microns)	Temperature=30`C	Po=176.84N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 30`C =1.163kg/m^3	**U=17.44m/s**	Reynold's no.,Re=2.817*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	11.8	16.8	61.509504	0.589767825	0.241941738
33	1.2	12.2	17.2	92.264256	0.722315119	0.200575988
32	2.2	12.6	17.6	123.019008	0.834057656	0.138405482
31	3.2	12.9	17.9	146.085072	0.908893259	0.082806303
30	4.2	13.1	18.1	161.462448	0.955533086	0.042489608
29	5.2	13.2	18.2	169.151136	0.978019294	0.021497555
28	6.2	13.3	18.3	176.839824	1	0
27	7.2	13.3	18.3	176.839824	1	0

Table 6.10: Rough Surface (150 microns)	Temperature=29`C	Po=315.236N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 29`C =1.167kg/m^3	**U=23.24m/s**	Reynold's no., Re=3.767*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	12.5	17.5	115.33032	0.604858379	0.23900472
33	1.2	13.1	18.1	161.462448	0.715678085	0.203482963
32	2.2	13.7	18.7	207.594576	0.811502671	0.152966086
31	3.2	14.2	19.2	246.038016	0.883452209	0.102964404
30	4.2	14.6	19.6	276.792768	0.937042571	0.058993791
29	5.2	14.9	19.9	299.858832	0.97530483	0.024085318
28	6.2	15	20	307.54752	0.987729597	0.012119841
27	7.2	15.1	20.1	315.236208	1	0
26	8.2	15.1	20.1	315.236208	1	0



Velocity Distribution (150 microns)
Y (Distance from the surface in mm) - - >
u/U (Velocity Ratio) - - >
0
1
2
3
4
5
6
7
8
9
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
U=17.44 m/s
U=23.24 m/s

Fig.:-6.8

6.10 Grain Size: 125 micron[redacted].

Velocity 17.44 m/s.

Room Temperature: 30°C (303.15 K)

Air flow bench pressure(P_o): 176.84 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 17.44 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

$$Re = 2.817 \times 10^5$$

Velocity 23.24 m/s.

Room Temperature: 29°C (302.15 K)

Air flow bench pressure(P_o): 315.236 N/mm^2

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\rho U^2 = P_o$$

$$U = 23.24 \text{ m/sec.}$$

The Reynold Number is then obtained by the equation given below:

$$Re = UL/\nu$$

$$Re = 3.767 \times 10^5$$

Table 6.11: Rough Surface (125 microns)

Rough Surface (125 microns)	Temperature=30`C	Po=176.84N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 30`C =1.163kg/m^3	**U=17.44m/s**	Reynold's no., Re=2.817*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	12	17	76.88688	0.659380473	0.224597865
33	1.2	12.3	17.3	99.952944	0.751809412	0.18659202
32	2.2	12.7	17.7	130.707696	0.859726954	0.120596519
31	3.2	12.9	17.9	146.085072	0.908893259	0.082806303
30	4.2	13.1	18.1	161.462448	0.955533086	0.042489608
29	5.2	13.2	18.2	169.151136	0.978019294	0.021497555
28	6.2	13.3	18.3	176.839824	1	0
27	7.2	13.3	18.3	176.839824	1	0

Table 6.12: **Rough Surface (125 microns)**	Temperature=29`C	Po=315.236N/mm^2	Sp. Gravity of Manometer fluid=.784	air density at 29`C =1.167kg/m^3	**U=23.24m/s**	Reynold's no., Re=3.767*10^5
scale reading	distance(mm)	manometer reading	relative distance(cm)	Pt(N/mm^2)	u/U	u/u(1-u/U)
34	0.2	12.5	17.5	115.33032	0.604858379	0.23900472
33	1.2	13.1	18.1	161.462448	0.715678085	0.203482963
32	2.2	13.6	18.6	199.905888	0.796333059	0.162186718
31	3.2	14.2	19.2	246.038016	0.883452209	0.102964404
30	4.2	14.6	19.6	276.792768	0.937042571	0.058993791
29	5.2	14.9	19.9	299.858832	0.97530483	0.024085318
28	6.2	15	20	307.54752	0.987729597	0.012119841
27	7.2	15.1	20.1	315.236208	1	0
26	8.2	15.1	20.1	315.236208	1	0
25	9.2	15.1	20.1	315.236208	1	0

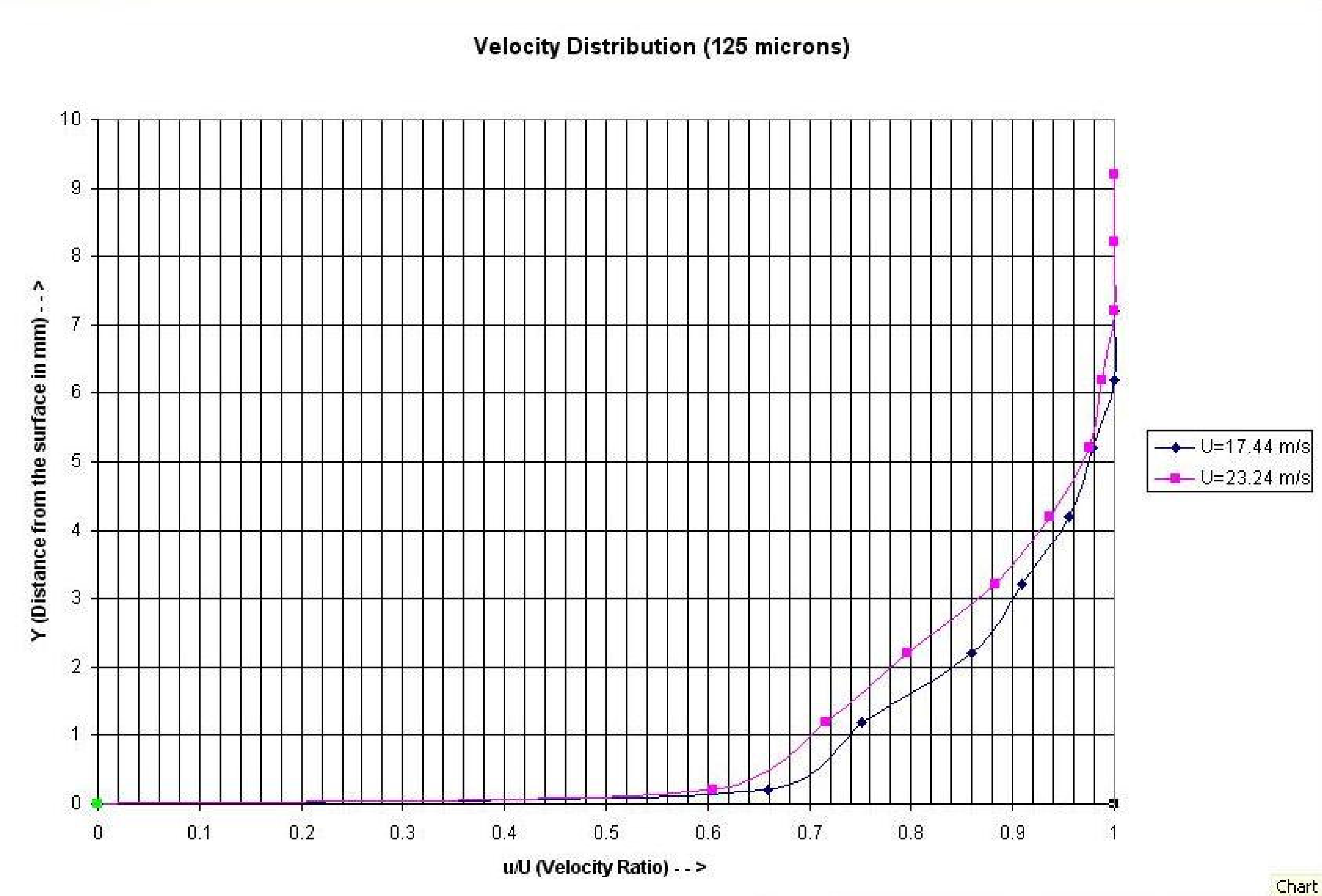

Velocity Distribution (125 microns)
Y (Distance from the surface in mm) - - >
u/U (Velocity Ratio) - - >
U=17.44 m/s
U=23.24 m/s
0
1
2
3
4
5
6
7
8
9
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Fig.:-6.9

Velocity Distribution at Reynold's Number ($Re=2.8x10^5$) for different Surfces

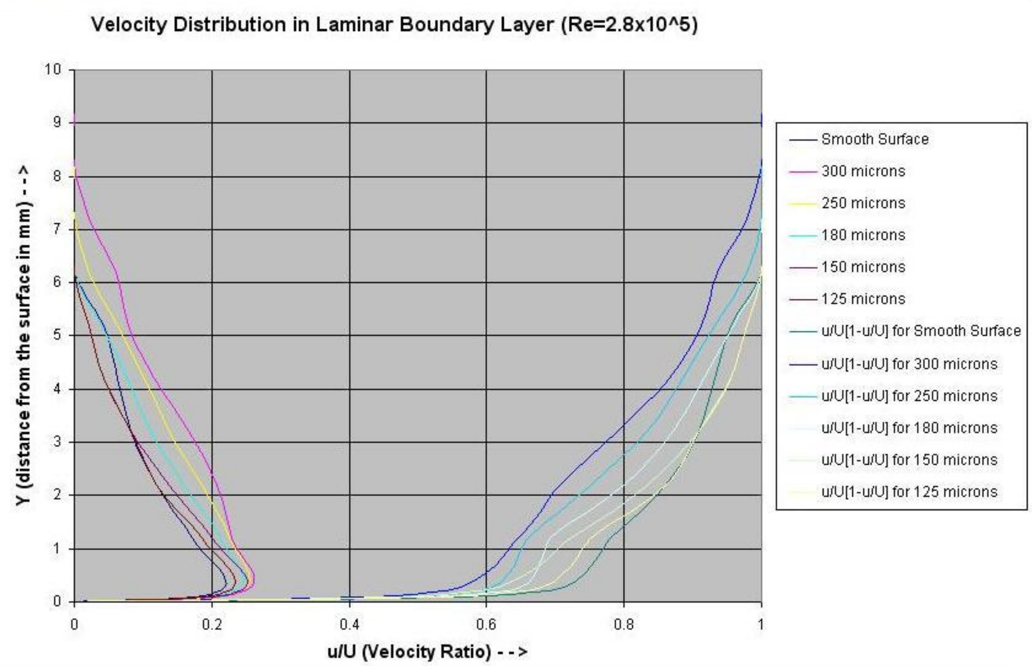


Fig.:-6.10

Velocity Distribution at Reynold's Number ($Re=3.7\ x10^5$) for different Surfaces

Fig.:-6.11

6.11 DISPLACEMENT THICKNESS AND SHEAR STRESS OF SMOOTH SURFACE

From the graph of velocity U=17.53 m/s the equation formulated is :

$u/U = -0.0061(y^2/\delta^2)+0.0879(y/\delta)+0.682$

Using this equation, the boundary layer thickness (δ) obtained is 0.4435 mm.

The shear stress obtained from the formula

$\tau_o = \mu(\partial u/\partial y)$ at y=0

$= 0.0879U\mu/\delta$

$= 0.0625$ kg/m^2

6.12 DISPLACEMENT THICKNESS AND SHEAR STRESS OF ROUGH SURFACE OF 300micron GRAIN SIZE

From the graph of velocity U=17.78 m/s the equation formulated is :

$u/U = -0.0055(y^2/\delta^2)+0.1028(y/\delta)+0.5207$

Using this equation, the boundary layer thickness (δ) obtained is 1.3978 mm.

The shear stress obtained from the formula

$\tau_o = \mu(\partial u/\partial y)$ at y=0

$= 1.1028U\mu/\delta$

$= 0.2525$ kg/m^2

Table 6.13: BOUNDARY LAYER PARAMETERS CALCULATED ON VARIOUS SURFACES

Type of Surface	Boundary Layer Thickness (mm)	Displacement Thickness (mm)	Momentum Thickness (mm)
Smooth Surface	0.4435	0.12243	0.0884
125 microns	0.4895	0.1511	0.102
150 microns	0.5240	0.1927	0.1554
180 microns	0.5918	0.2263	0.1986
250 microns	0.9824	0.4283	0.2806
300 microns	1.3978	0.6	0.342

CONCLUSION

The Reynold number so obtained ranges is less than 5×10^5. It concludes that the velocity distribution observed is in the Laminar Boundary Layer .The reduction in velocity near the smooth surface is found to be nearly 30% as compared to 46% reduction in the velocity for 300 micron rough surface.

Also it has been found that reduction in velocity increases with the increase in free stream velocity.

The variation in displacement thickness from smooth surface to rough surface of 300 micron grain size is found to be in the range of 0.44mm to 1.4mm.

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